US007791574B2

(12) United States Patent
Kamijo et al.

(10) **Patent No.:** **US 7,791,574 B2**
(45) **Date of Patent:** **Sep. 7, 2010**

(54) **ELECTRO-OPTICAL DEVICE AND ELECTRONIC APPARATUS**

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(73) Assignee: **Seiko Epson Corporation** (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 878 days.

(21) Appl. No.: **11/208,895**

(22) Filed: **Aug. 22, 2005**

(65) **Prior Publication Data**

US 2006/0044239 A1 Mar. 2, 2006

(30) **Foreign Application Priority Data**

Sep. 1, 2004 (JP) 2004-253840

(51) **Int. Cl.**
G09G 3/34 (2006.01)
G06F 3/038 (2006.01)
G02F 1/1335 (2006.01)

(52) **U.S. Cl.** **345/88**; 349/114; 349/107

(58) **Field of Classification Search** 345/695, 345/89, 82, 88, 204, 81, 90; 349/106, 107, 349/114

See application file for complete search history.

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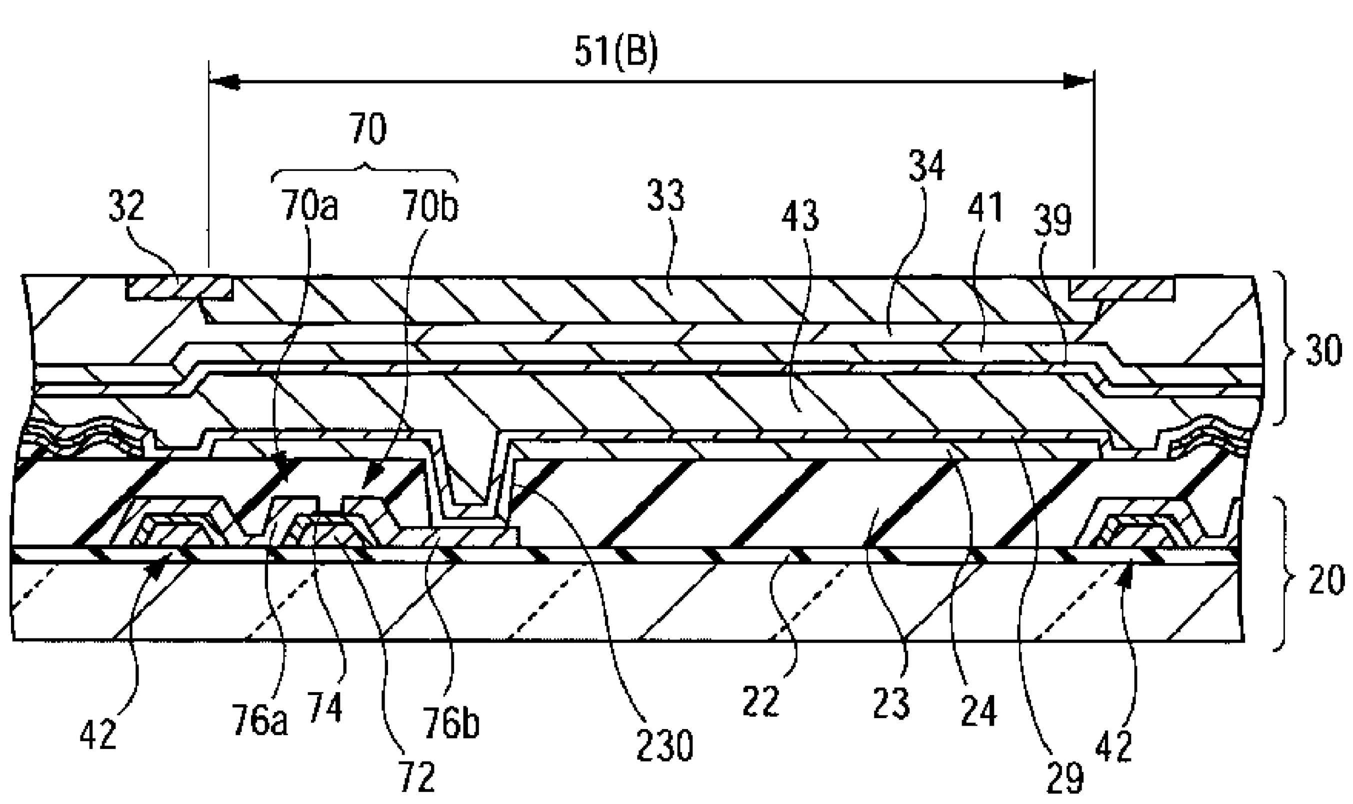
(57) **ABSTRACT**

There is provided an electro-optical device including pixels arranged in a matrix, each pixel having a plurality of color-display sub-pixels corresponding to a plurality of colors and a monochrome-display sub-pixel. The color-display sub-pixel and the monochrome-display sub-pixel can perform gray-scale display independently. One of the color-display sub-pixel and the monochrome-display sub-pixel displays images in a transmissive mode in which light emitted from a light source is modulated, while the other sub-pixel displays images in a reflective mode in which light incident from outside is modulated.

7 Claims, 7 Drawing Sheets



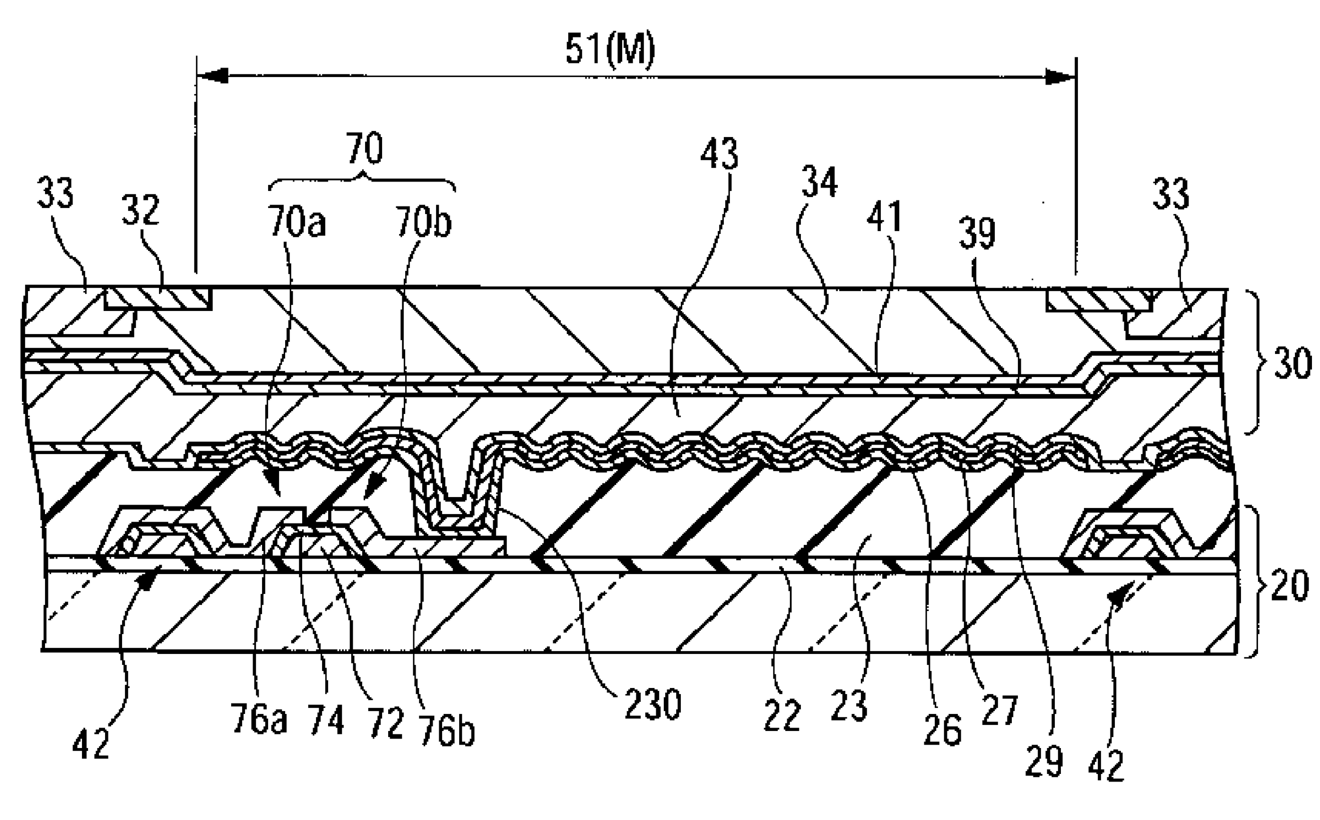
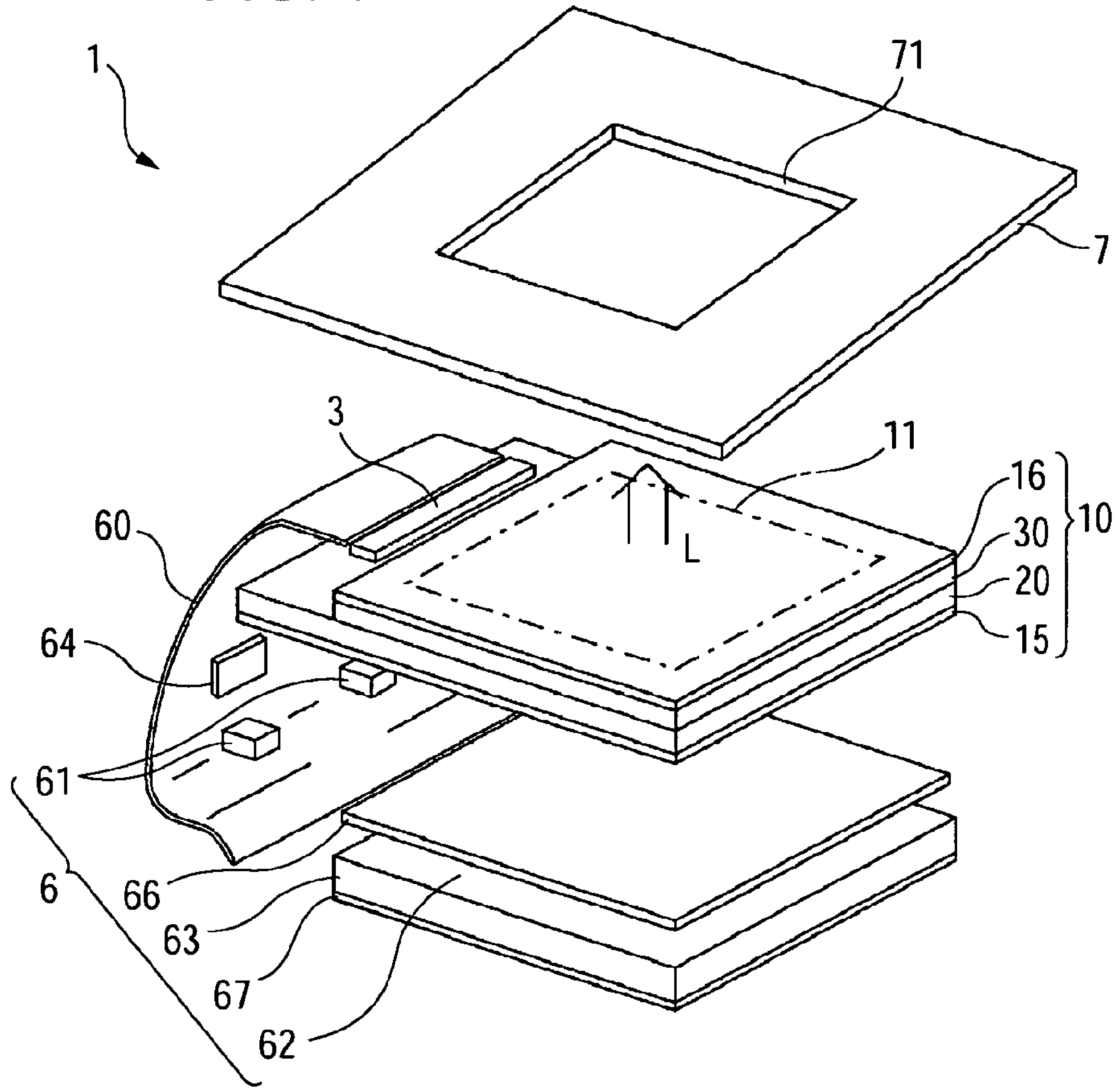
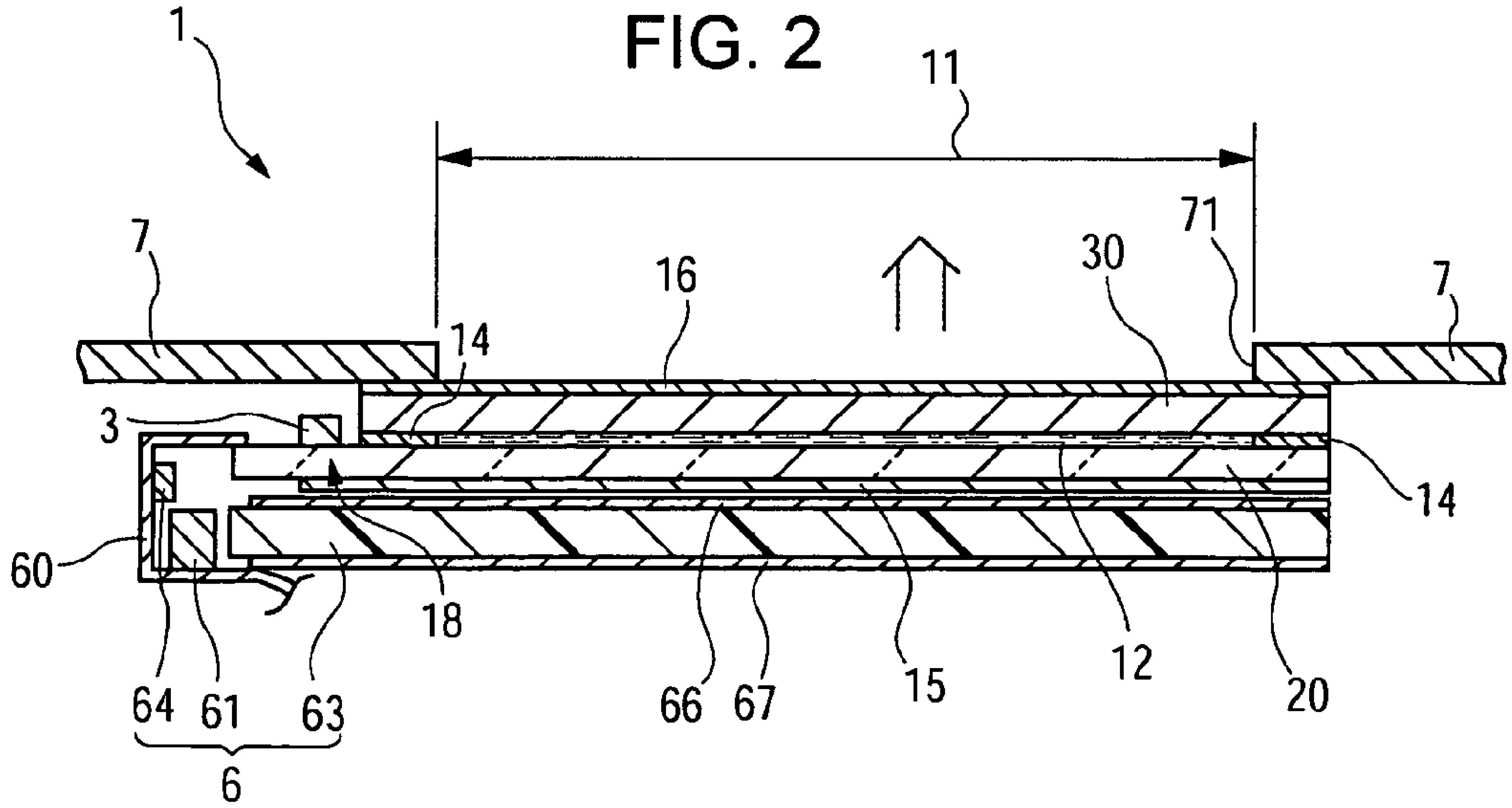


FIG. 1



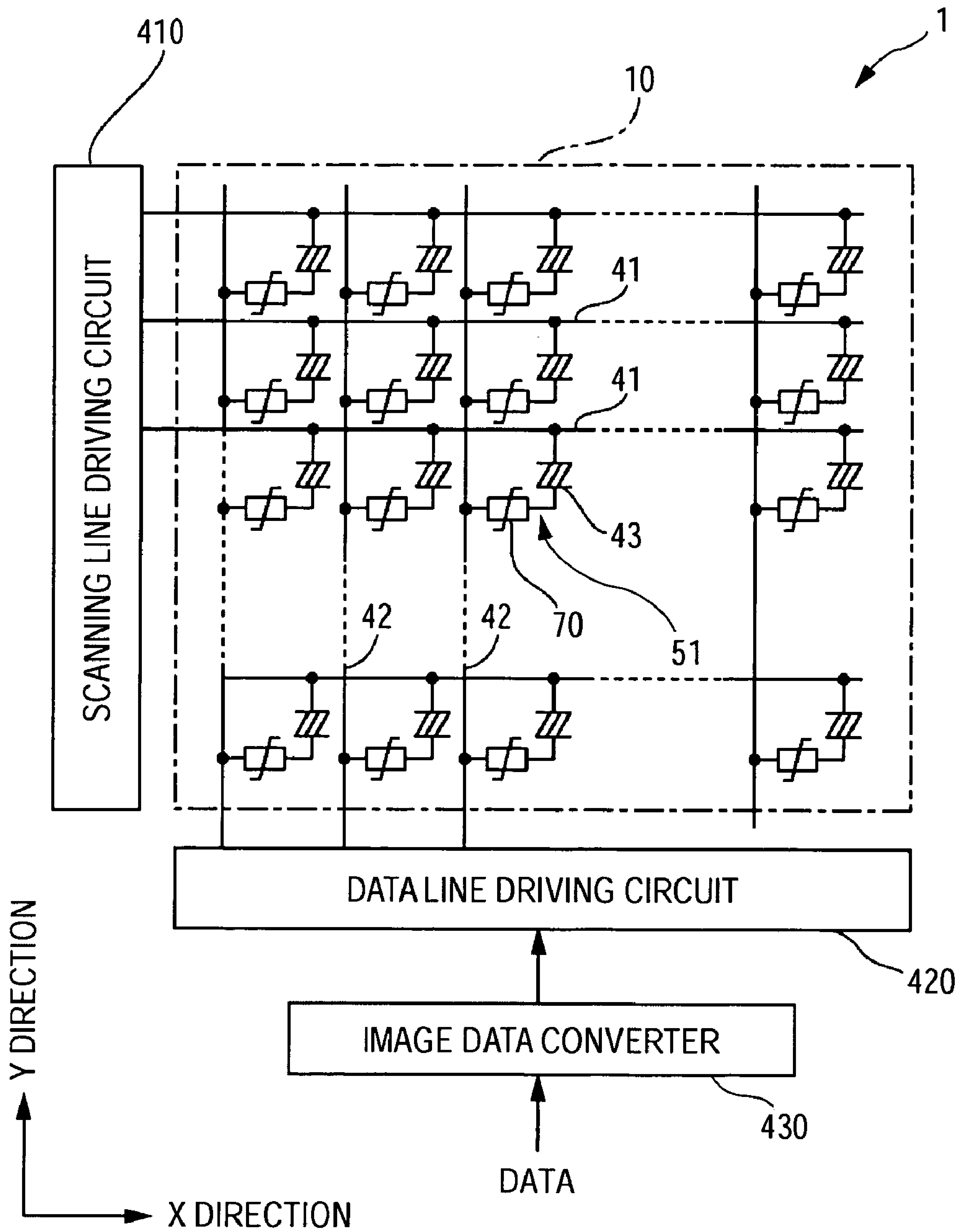
1
71
7
3
11
16
30
10
20
15
L
60
64
61
6
66
63
67
62

FIG. 2



1
11
7
71
7
16
30
14
3
14
60
18
66
67
15
12
20
64
61
63
6

FIG. 3



410
1
10
SCANNING LINE DRIVING CIRCUIT
41
41
43
42
42
70
51
DATA LINE DRIVING CIRCUIT
420
IMAGE DATA CONVERTER
430
DATA
Y DIRECTION
X DIRECTION

FIG. 4

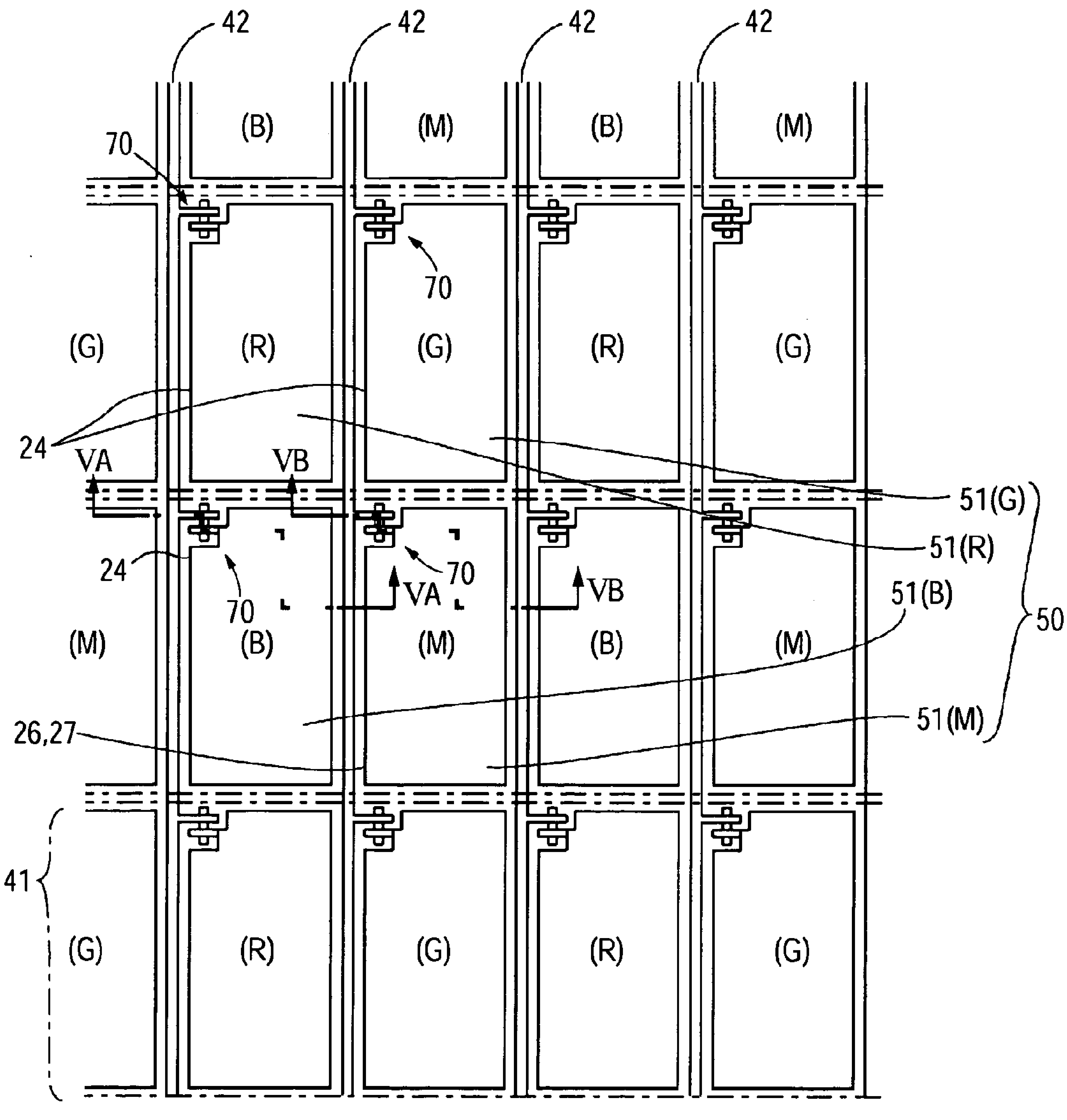

42
42
42
42
(B)
(M)
(B)
(M)
70
70
(G)
(R)
(G)
(R)
(G)
24
VA
VB
51(G)
51(R)
24
70
VA
70
VB
51(B)
50
(M)
(B)
(M)
(B)
(M)
26,27
51(M)
41
(G)
(R)
(G)
(R)
(G)

FIG. 5A

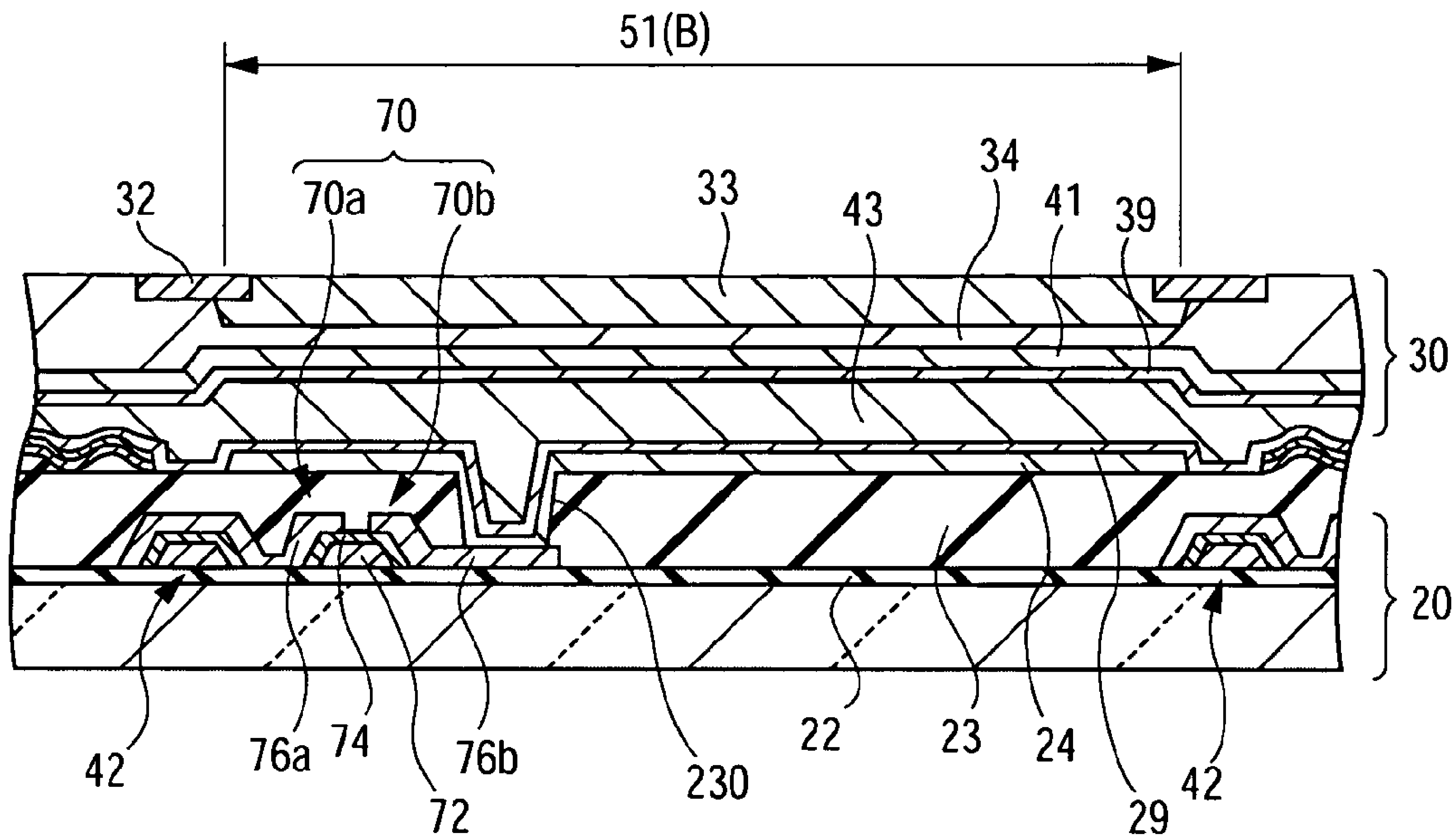

51(B)
70
32
70a
70b
33
43
34
41
39
30
20
42
76a
74
72
76b
230
22
23
24
29
42

FIG. 5B

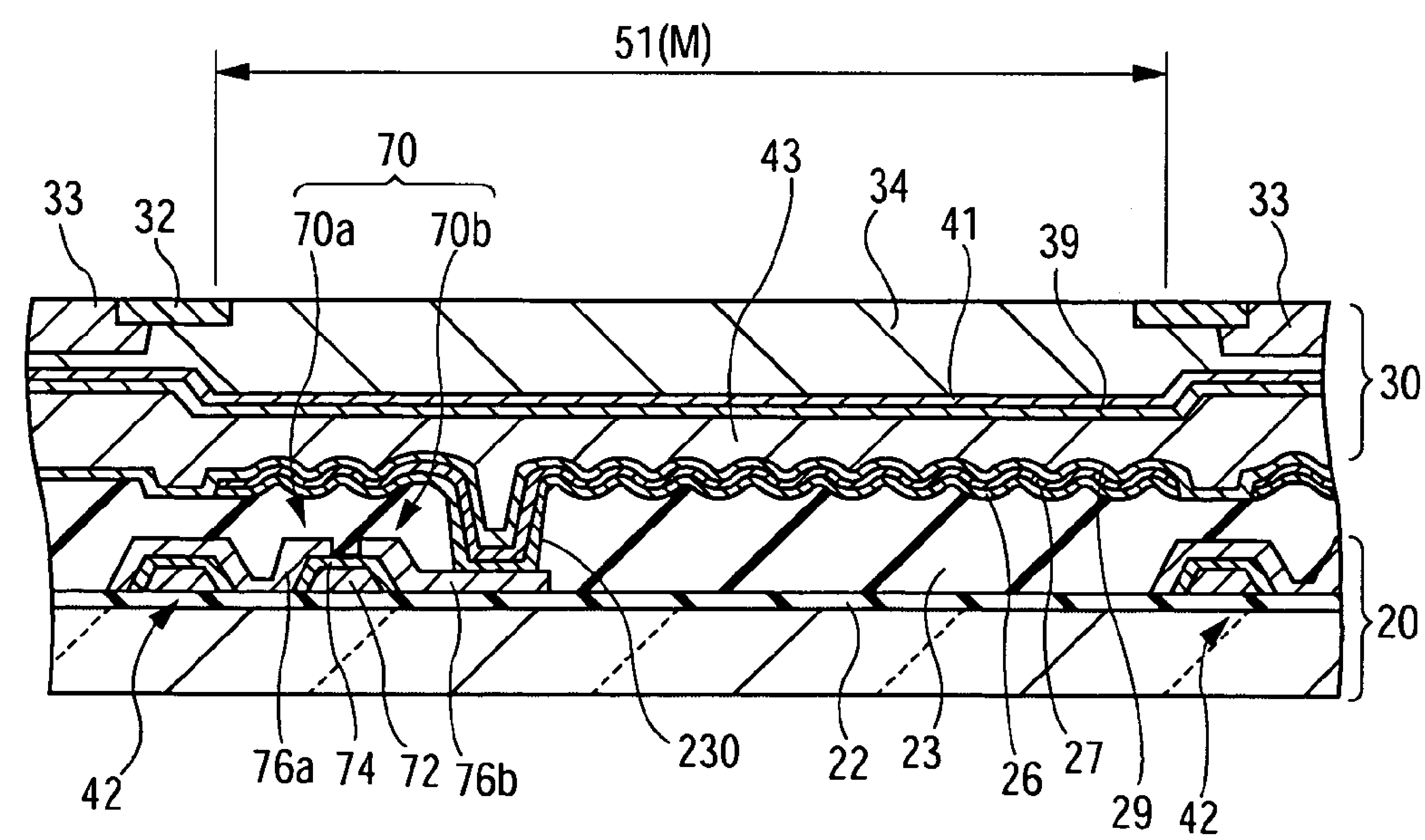
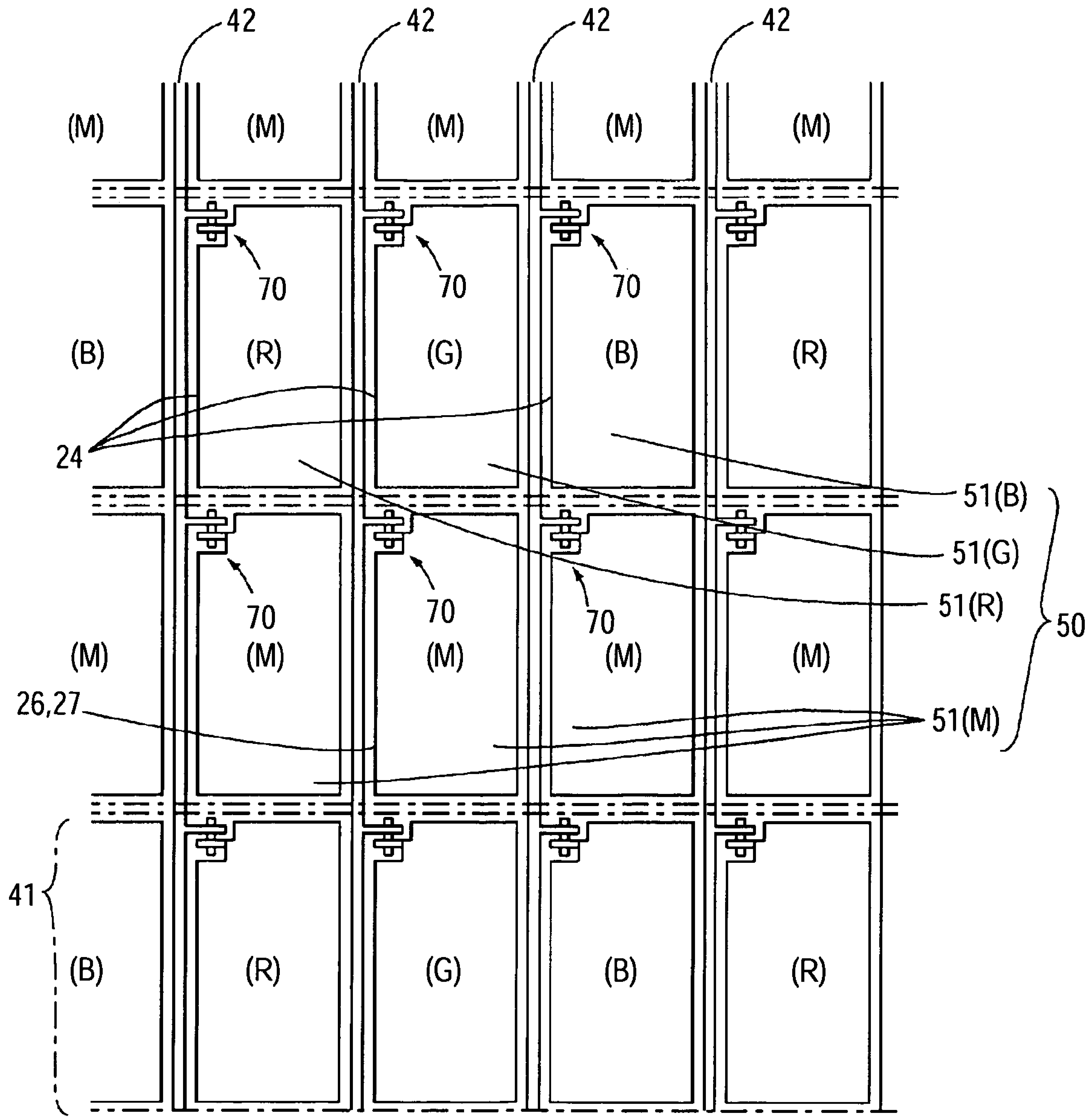

51(M)
70
33
32
70a
70b
43
34
41
39
33
30
20
42
76a
74
72
76b
230
22
23
26
27
29
42

FIG. 6


42
42
42
42
(M)
(M)
(M)
(M)
(M)
70
70
70
(B)
(R)
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(B)
(R)
24
51(B)
51(G)
51(R)
50
70
70
70
(M)
(M)
(M)
(M)
(M)
26,27
51(M)
41
(B)
(R)
(G)
(B)
(R)

FIG. 7

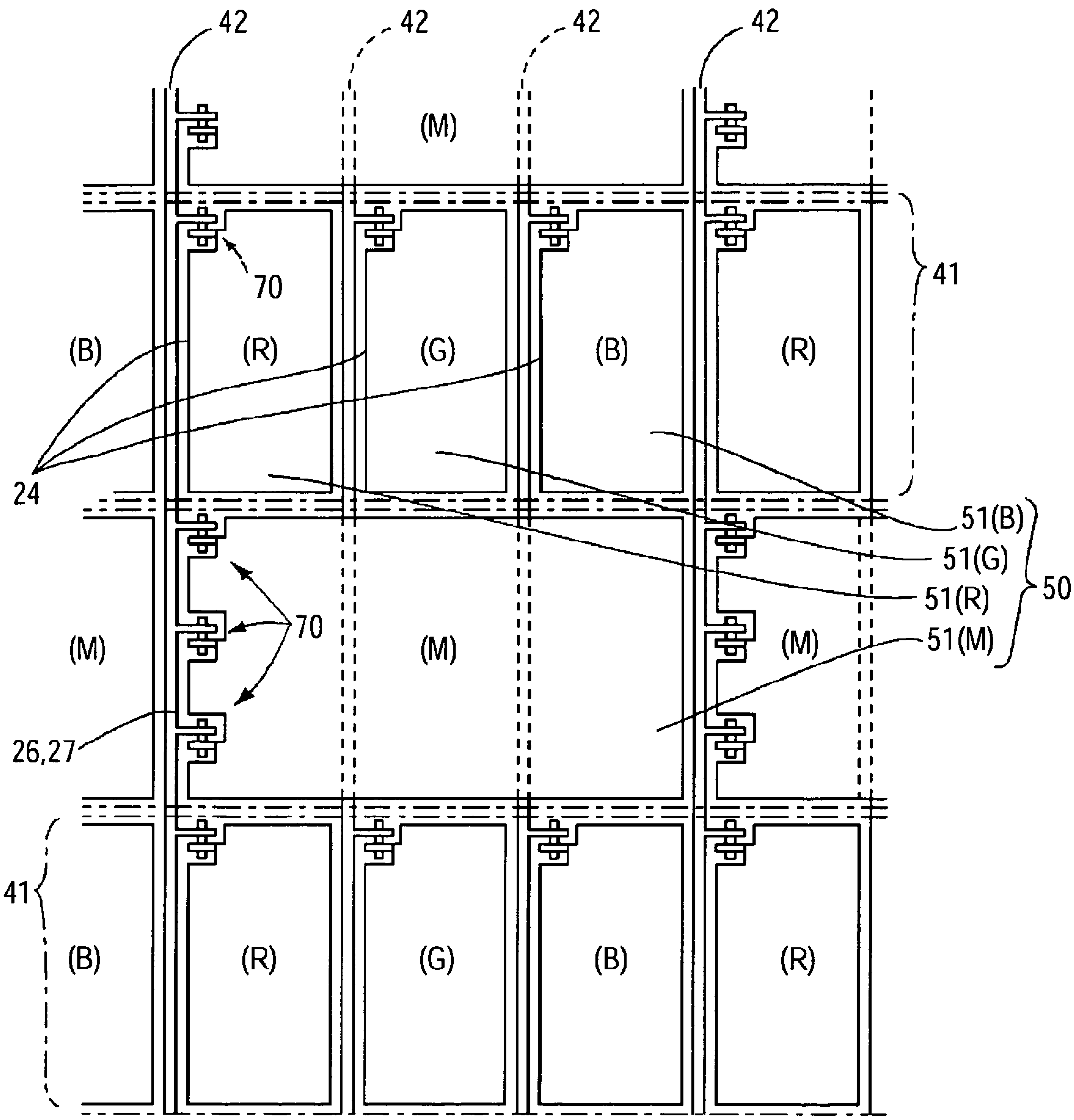

42
42
42
42
(M)
70
41
(B)
(R)
(G)
(B)
(R)
24
51(B)
51(G)
51(R)
50
70
(M)
(M)
(M)
51(M)
26,27
41
(B)
(R)
(G)
(B)
(R)

FIG. 8A

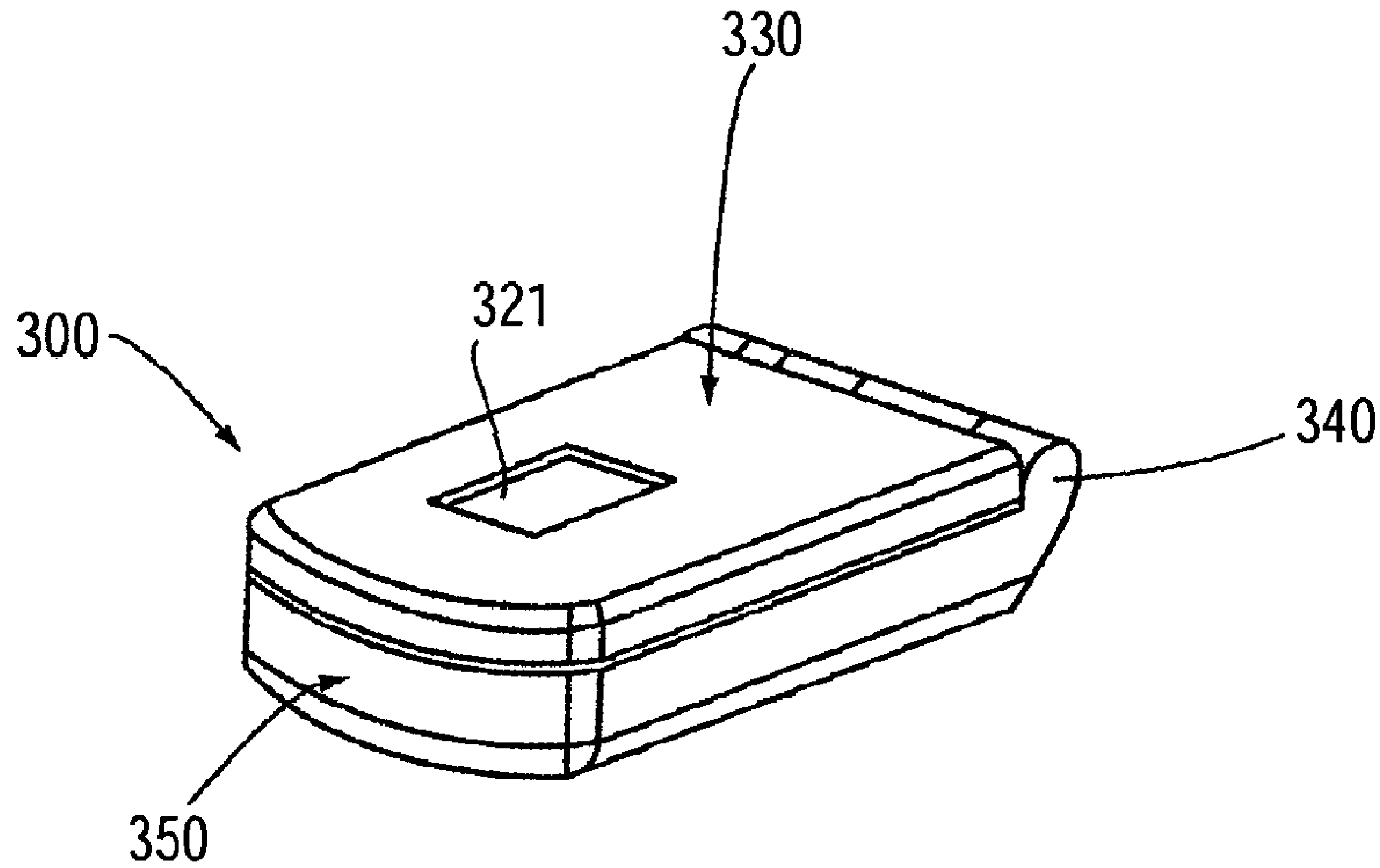
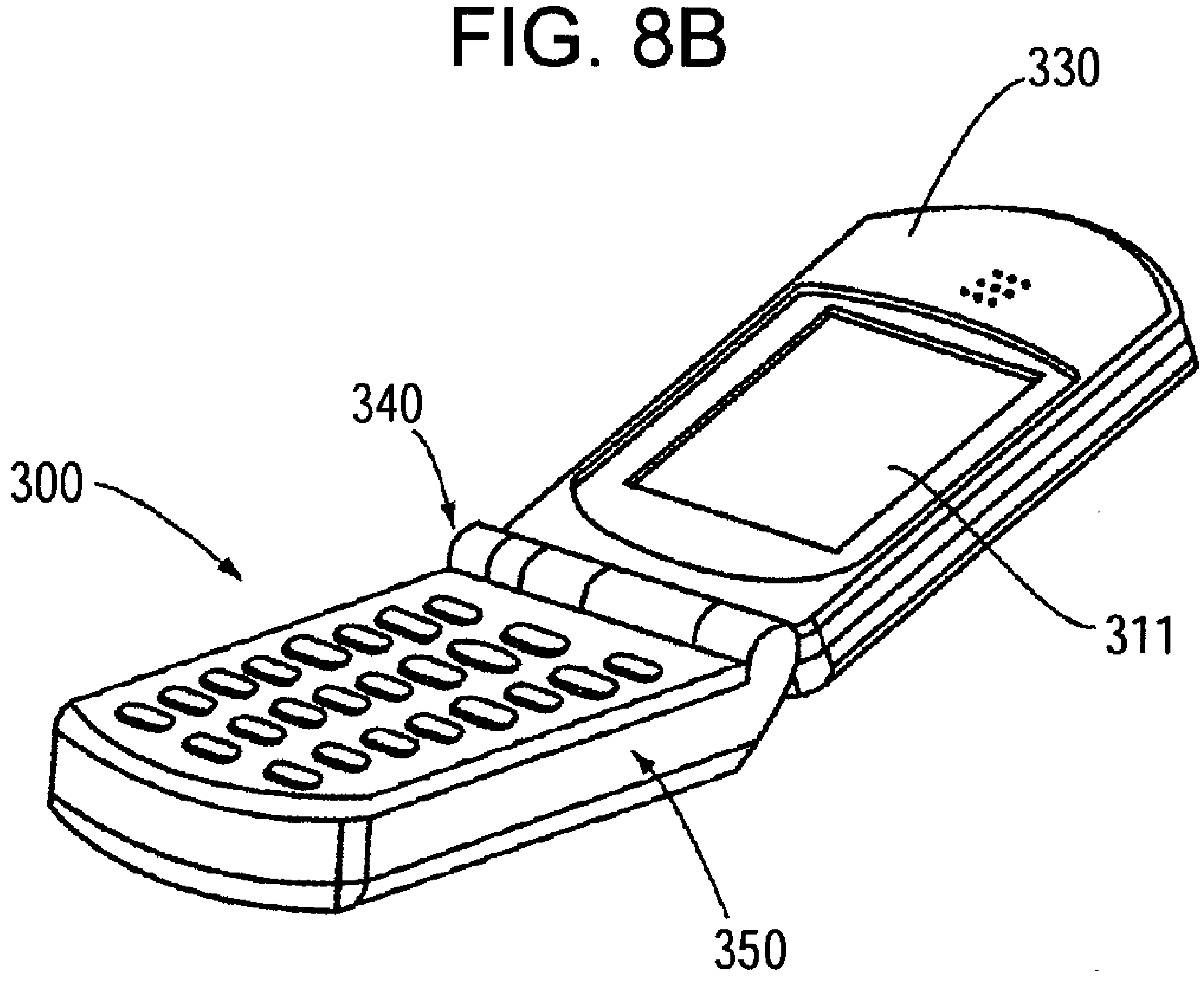


FIG. 8B



ELECTRO-OPTICAL DEVICE AND ELECTRONIC APPARATUS

RELATED APPLICATIONS

This application claims priority to Japanese Patent Application No. 2004-253840 filed Sep. 1, 2004 which is hereby expressly incorporated by reference herein in its entirety.

BACKGROUND OF THE INVENTION

1. Technical Field

The present invention relates to an electro-optical device capable of displaying images in transmissive and reflective modes, and to an electronic apparatus having the electro-optical device.

2. Related Art

In active-matrix-type electro-optical devices, pixels having a plurality of color-display sub-pixels respectively corresponding to a plurality of colors are arranged in a matrix. Also, images can be displayed in transmissive and reflective modes if a reflective layer is formed on each sub-pixel and a light transmissive portion is formed by removing a part of the reflective layer (for example, see Japanese Unexamined Patent Application Publication No. 2004-77544).

However, a transflective electro-optical device disclosed in Japanese Unexamined Patent Application Publication No. 2004-77544, in which external light is required to display color images in a reflective mode, has a problem in that the amount of light is limited. As a result, high-quality color images cannot be obtained, and thus it is difficult to read displayed information.

SUMMARY

An advantage of the invention is that it provides an electro-optical device in which information displayed in a reflective mode can be easily read, and an electronic apparatus having the electro-optical device.

According to an aspect of the invention, there is provided an electro-optical device including pixels arranged in a matrix, each pixel having a plurality of color-display sub-pixels corresponding to a plurality of colors and a monochrome-display sub-pixel. The color-display sub-pixel and the monochrome-display sub-pixel can perform gray-scale display independently. One of the color-display sub-pixels and the monochrome-display sub-pixel displays an image in a transmissive mode in which light emitted from a light source is modulated, while the other type of sub-pixel displays an image in a reflective mode in which light incident from outside is modulated.

According to the invention, for example, it is possible to display color images in a transmissive mode by means of the color-display sub-pixels and to display monochrome images in a reflective mode by means of the monochrome-display sub-pixel. In this case, since external light is required to display images in the reflective mode, the amount of light is limited. However, since monochrome images are displayed in the reflective mode, the light will not transmit a color filter layer unlike a case in which color images are displayed. Thus, since light loss upon transmitting the color filter layer does not occur in the reflective mode, bright images can be displayed so that displayed information can be easily read. Also, color signals displayed in the monochrome mode are displayed in gray-scale which is difficult to be discriminated. However, according to the invention, different image signals can be supplied to the monochrome-display sub-pixel and the color-display sub-pixel. Accordingly, it is possible to display high-quality color images in the transmissive mode and to display high-quality monochrome images in the reflective mode.

In the electro-optical device according to the aspect of the invention, it is preferable that, in each pixel, different image signals be supplied to the color-display sub-pixels and the monochrome-display sub-pixel, respectively.

Further, in the electro-optical device according to the aspect of the invention, it is preferable that the color-display sub-pixel display an image in a transmissive mode and the monochrome-display sub-pixel display an image in a reflective mode.

In this case, it is preferable that an electro-optical material layer interposed between a pair of substrates to modulate light be further provided. Further, it is preferable that the electro-optical material layer be thicker in the color-display sub-pixels than in the monochrome-display sub-pixel. Light transmits the electro-optical material layer twice in the reflective mode, while light transmits the electro-optical material layer once in the transmissive mode. However, by making the electro-optical material layer in the color-display sub-pixel thicker, it is possible to optimize retardation both in the color-display sub-pixel and in the monochrome-display sub-pixel.

Furthermore, in the electro-optical device according to the aspect of the invention, it is preferable that, when the sub-pixels are electrically connected to signal lines through pixel switching elements, respectively, the respective sub-pixels have the same sub-pixel area with respect to each switching element. Also, it is preferable that, when the color-display sub-pixels and the monochrome-display sub-pixel are electrically connected to signal lines through pixel switching elements, respectively, the color-display sub-pixels and the monochrome-display sub-pixel be equal in the number of switching elements with respect to an area of the sub-pixel. With such a configuration, when a TFD element is used as a non-linear element, an equal capacitance ratio can be obtained both in the transmissive mode and in the reflective mode, so that an equal driving voltage can be applied. Also, when the capacitance ratio can be made to be approximately equal in both modes, the same effect can be achieved even though the areas are not equal to each other.

Moreover, in the electro-optical device according to the aspect of the invention, it is preferable that, in the pixel, among four sub-pixels arranged in a lattice shape, three sub-pixels be the color-display sub-pixels and the remaining one sub-pixel be the monochrome-display sub-pixel.

In addition, in the electro-optical device according to the aspect of the invention, it is preferable that, in the pixel, a row on which the three color-display sub-pixels are arranged and a row on which the monochrome-display sub-pixels are arranged be provided parallel to each other.

Further, according to another aspect of the invention, the electro-optical device according to the invention can be applied to an electronic apparatus such as mobile phones or mobile computers.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements, and wherein:

FIG. **1** is an exploded perspective view of an electro-optical device according to the invention;

FIG. **2** is a cross-sectional view of the electro-optical device shown in FIG. **1**;

FIG. **3** is a block diagram showing an electrical configuration of the electro-optical device shown in FIG. **1**;

FIG. **4** is an explanatory view showing the configuration of a pixel in plan view, in an electro-optical device according to a first embodiment of the invention;

FIG. **5**A is a cross-sectional view of a color-display sub-pixel taken along line VA-VA of FIG. **4**, in an electro-optical device according to the invention;

FIG. **5**B is a cross-sectional view of a monochrome-display sub-pixel taken along line VB-VB of FIG. **4**, in the electro-optical device according to the invention;

FIG. **6** is an explanatory view showing the configuration of a pixel in the electro-optical device according to a second embodiment of the invention;

FIG. **7** is an explanatory view showing the configuration of a pixel in the electro-optical device according to a third embodiment of the invention;

FIG. **8**A is an explanatory view showing an open state of a flip-type mobile phone, which is an example of an electronic apparatus according to the invention; and

FIG. **8**B is an explanatory view showing a closed state of a flip-type mobile phone, which is an example of the electronic apparatus according to the invention.

DESCRIPTION OF THE EMBODIMENTS

Hereinafter, preferred embodiments of the invention will be described with reference to the accompanying drawings. The scale of each member has been adjusted in order to have a recognizable size in the drawings described below.

First Embodiment

Overall Configuration of Electro-Optical Device

FIG. **1** is an exploded perspective view of an electro-optical device to which the invention is applied. FIG. **2** is a cross-sectional view of the electro-optical device shown in FIG. **1**. FIG. **3** is a block diagram showing an electrical configuration of the electro-optical device shown in FIG. **1**. FIG. **4** is an explanatory view showing a configuration of a pixel in plan view, in an electro-optical device according to a first embodiment of the invention. In FIG. **4**, although a pixel-electrode is formed to cover a TFD element, a part of the pixel electrode is cut away to show the TFD element so that the presence of a component can be easily understood.

As shown in FIGS. **1** and **2**, an electro-optical device **1** according to the present embodiment includes a backlight **6**, an electro-optical panel **10**, and a light-shielding frame **7**, which are stacked in the above order. The frame **7** includes a light transmissive area **71** formed corresponding to an image display area **11** of the electro-optical panel **10** so that a user can view images displayed in the image display area **11** of the electro-optical panel **10**.

The backlight **6** includes a plurality of LEDs **61** (light emitting devices) serving as light sources, and a light-guiding plate **63** which is made of resin and in which light emitted from the LEDs **61** is incident on a lateral side thereof to be emitted from a light-emitting surface **62** thereof. The light-emitting surface **62** of the light-guiding plate **63** and the electro-optical panel **10** are provided opposite to each other. In the backlight **6**, for example, a light-scattering sheet **66** is provided on the light-emitting surface **62** side of the light-guiding plate **63**, and a prism sheet **67** is provided on the opposite side thereof.

The electro-optical panel **10** is, for example, an active-matrix-type color liquid crystal panel. A polarizer **15**, which is provided on a side on which light is incident, and a polarizer **16**, which is provided on a side from which light is emitted, are stacked on both sides of the electro-optical panel **10**. As will be described later, the electro-optical panel **10** includes an element substrate **20**, on which pixel electrodes or TFD elements are formed, a counter substrate **30**, on which counter electrodes or color filters are formed, and a liquid crystal layer **12** interposed therebetween. The element substrate **20** and the counter substrate **30** are bonded by a sealing material **14** to have a predetermined distance therebetween. In the present embodiment, the counter substrate **30** is provided at a side to which display light (denoted by arrow L) is emitted, while the element substrate **20** is provided at the opposite side.

The element substrate **20** is larger than the counter substrate **30**. On an extended area **18** of the element substrate **20** extended from the counter substrate **30**, a panel driving IC **3** is mounted in a COG (chip on glass) manner. The panel driving IC **3** includes a data line driving circuit **420** or a scanning line driving circuit **410**, and a power, supply circuit generating voltage to be used in the electro-optical device **1**. Also, an end portion of a flexible substrate **60** for supplying signals or electrical power to the panel driving IC **3** is mounted on the extended area **18** of the electro-optical panel **10**. On the flexible substrate **60**, LEDs **61** of the backlight **6** are mounted and an LED driving IC **64** including an LED driving circuit for driving the LEDs **61** is also mounted. The LED driving IC **64** supplies current with a predetermined duty ratio. The flexible substrate **60** is disposed from the electro-optical panel **10** to the light-guiding plate **63**. Also, the flexible substrate **60** is disposed such that the axis of emitted light from the LED **61** is parallel to the lateral side of the light-guiding plate **63**.

As shown in FIGS. **3** and **4**, in the electro-optical panel **10**, a plurality of scanning lines **41** are arranged in a row direction (X-direction), while a plurality of data lines **42** are arranged in a column direction (Y-direction). Also, a plurality of sub-pixels **51** are arranged in a matrix to correspond to the respective intersections between the scanning lines **41** and the data lines **42**. In each sub-pixel **51**, a liquid crystal layer **43**, composed of nematic liquid crystal, and a TFD element **70**, which is a two-terminal-type active element, are connected in series to each other. Although the liquid crystal layer **43** is connected to the scanning line **41** and the TFD element **70** is connected to the data line **42** in the present embodiment, the liquid crystal layer **43** may be connected to the data line **42** and the TFD element **70** may be connected to the scanning line **41**. In either case, the scanning line **41** is driven by a scanning line driving circuit **410** and the data line **42** is driven by a data line driving circuit **420**.

As will be described below, the electro-optical panel **10** according to the present embodiment can display both color images and monochrome images. When the color images and the monochrome images are displayed, different image signals are supplied, so that optimum images can be displayed in either case. For this reason, with respect to the data driving circuit **420**, an image data converter **430**, which converts a signal for displaying the color image to a signal for displaying the monochrome image, is included in the panel driving IC **3**.

Detailed Configuration of Pixel

FIGS. **5**A and **5**B are a cross-sectional view of a color-display sub-pixel taken along line VA-VA of FIG. **4** and a cross-sectional view of a monochrome-display sub-pixel taken along line VB-VB of FIG. **4**, respectively, in an electro-optical device according to the invention.

As shown in FIG. **4**, in the electro-optical device **1** according to the present embodiment, a single pixel **50** includes color-display sub-pixels **51**(R), **51**(G), and **51**(B) corresponding to red (R), green (G), and blue (B), respectively, and a monochrome-display sub-pixel **51**(M). That is, the single pixel **50** is composed of four sub-pixels arranged in a lattice shape, each of which has an equal area. Three of them are color-display sub-pixels **51**(R), **51**(G), and **51**(B), and the remaining one is a monochrome-display sub-pixel **51**(M).

The respective sub-pixels **51**(R), **51**(G), **51**(B), and **51**(M) are connected to the data lines **42** through the TFD elements **70**, respectively. Accordingly, predetermined image signals can be supplied to the respective sub-pixels **51**(R), **51**(G), **51**(B), and **51**(M). That is, in each pixel **50**, different image signals can be supplied to the color-display sub-pixels **51**(R), **51**(G), and **51**(B) and the monochrome-display sub-pixel **51**(M).

As will be described below with reference to FIGS. **5**A and **5**B, the present embodiment is configured such that the color-display sub-pixels **51**(R), **51**(G), and **51**(B) display images in a transmissive mode in which light emitted from the backlight **6** is modulated, and the monochrome-display sub-pixel **51**(M) displays images in a reflective mode in which light incident from outside is modulated.

As shown in FIG. **5**A, in the color-display sub-pixels **51**(R), **51**(G), and **51**(B), a transmissive base film **22** is formed on a surface of a transmissive member, such as glass, of the element substrate **20**. On a surface of the base film **22**, a plurality of data lines **42** and a plurality of TFD elements **70** connected to the data lines **42** are formed. Also, on surfaces of the data lines **42** and the TFD elements **70**, an interlayer insulation film **23** made of a transmissive photosensitive resin is formed. On a surface of the interlayer insulation film **23**, transmissive pixel electrodes **24** made of ITO (Indium Tin Oxide) and an alignment film **29** are formed in this order. Contact holes **230** are formed on the interlayer insulation film **23**. The transmissive pixel electrodes **24** are electrically connected to the TFD elements **70** through the contact holes **230**, respectively. In the counter substrate **30**, a light-shielding film **32** and a color filter layer **33** having a predetermined color are formed on a surface of a transmissive member such as glass. On surfaces of the light-shielding film **32** and the color filter layer **33**, a transmissive planarization film **34**, transmissive scanning lines **41** (counter electrodes) made of, for example, stripe-shaped ITO, and an alignment film **39** made of polyimide resin are formed in this order. Thus, each color-display sub-pixel **51**(R), **51**(G), and **51**(B) is configured to correspond to any one of colors red (R), green (G), and blue (B), according to which color of red (R), green (G), and blue (B) is selected in the color filter layer **33**. Also, reflective layers are not formed on the color-display sub-pixels **51**(R), **51**(G), and **51**(B).

The TFD element **70** includes a first TFD element **70***a* and a second TFD element **70***b*. On an insulation film **22** formed on a surface of the element substrate **20** are formed a first metallic film **72**, an oxide film **74** which is made of an insulation material formed by performing anodic oxidation on the first metallic film **72**, and second metallic films **76***a* and **76***b* which are formed on the oxide film **74** and are separated from each other. Also, the second metallic film **76***a* is used as the data line **42**, while the second metallic film **76***b* is connected to the transmissive pixel electrode **24**. The first TFD element **70***a* is composed of the second metallic film **76***a*/oxide film **74**/first metallic film **72** in this order as viewed from the data line **42** side, i.e., a sandwich structure having metal (conductor)/insulator/metal (conductor). Thus, it has a bidirectional (positive/negative) diode switching characteristic. Meanwhile, the second TFD element **70***b* is composed of the first metallic film **72**/oxide film **74**/second metallic film **76***b* in this order as viewed from the data line **42** side. Thus, it has a diode switching characteristic opposite to that of first TFD element **70***a*. Accordingly, since the TFD element **70** is configured such that two diodes are serially connected in opposite directions to each other, the current-voltage non-linear characteristics become symmetrical both in the positive and negative directions, compared to a case of using a single diode. If the symmetrical non-linear characteristic is not required, a single TFD element **70** may be used. Also, the TFD element **70** is an example of a diode element. Other examples of the diode element include elements using a ZnO varistor or MSI (metal semi insulator), a combination of these elements, or such elements connected in series in opposite directions to each other or in parallel to each other.

As shown in FIG. **5**B, in the monochrome-display sub-pixel **51**(M), the base film **22** is formed on a surface of a transmissive member of the element substrate **20**. On a surface of the base film **22**, a plurality of data lines **42** and a plurality of TFD elements **70** connected to the data lines **42** are formed. Also, on surfaces of the data lines **21** and the TFD elements **40**, the interlayer insulation film **23** made of a transmissive photosensitive resin is formed. On a surface of the interlayer insulation film **23**, reflective pixel electrodes **26** (reflective layer) made of aluminum or silver, transmissive upper electrodes **27** made of IZO (indium zinc oxide), and an alignment film **29** are formed in this order. On a surface of the interlayer insulation film **23**, unevenness is randomly formed. Also, unevenness is formed on a surface of the reflective pixel electrode **26**. That is, if light reflected from the reflective pixel electrode **26** has a strong directionality, viewing angle dependency or the appearance of a background becomes noticeable. However, according to the present embodiment, when the interlayer insulation film **23** is formed on a lower layer of the reflective pixel electrode **26** using a photosensitive resin, an unevenness layer is formed by forming minute unevenness on the surface of the interlayer insulation film **23** to scatter light, thereby forming minute unevenness on the surface of the reflective pixel electrode **26**. The interlayer insulation film **23** is composed of one or two photosensitive resin layers. Also, the contact hole **230** is formed on the interlayer insulation film **23**. The reflective pixel electrode **26** is electrically connected to the TFD element **70** through the contact hole **230**. In the counter substrate **30**, a color filter layer is not formed in an area opposite to the reflective pixel electrode **26**. A planarization film **34**, stripe-shaped scanning lines **41** serving as counter electrodes, and an alignment film **39** made of polyimide resin are formed in this order in the counter substrate **30**. The configuration of the TFD element **70** is the same as that shown in FIG. **5**A and a detailed description thereof will thus be omitted herein.

Comparing the thickness of the planarization film **34** in the color-display sub-pixels **51**(R), **51**(G), and **51**(B) shown in FIG. **5**A with the thickness of the planarization film **34** in the monochrome-display sub-pixel **51**(M) shown in FIG. **5**B, the thickness of the planarization film **34** is small in the color-display sub-pixels **51**(R), **51**(G), and **51**(B) and is large in the monochrome-display sub-pixel **51**(M). Thus, although the color filter layer **33** is formed in the color-display sub-pixels **51**(R), **51**(G), and **51**(B), the liquid crystal layer **43** is thick. Meanwhile, although the color filter layer **33** is not formed in the monochrome-display sub-pixel **51**(M), the liquid crystal layer **43** is thin.

Operation and Main Effect of the Present Embodiment

In the electro-optical device **1** configured as described above, color images can be displayed in a transmissive mode using the color-display sub-pixels **51**(R), **51**(G), and **51**(B) and monochrome images can be displayed in a reflective mode using the monochrome-display sub-pixel **51**(M). Such a mode conversion is performed by user operation or automatically in an electronic apparatus equipped with the electro-optical device **1**. Here, such a mode conversion may occur while color images are being displayed in the transmissive mode or in the reflective mode. While the color images are being displayed, the monochrome-display sub-pixel **51**(M) is turned off. Also, while the monochrome images are being displayed, the color-display sub-pixels **51**(R), **51**(G), **51**(B) are turned off.

In the electro-optical device **1** configured as described above, since external light is used to display images in the reflective mode, the amount of light is limited. However, according to the present embodiment, since monochrome images are displayed in the reflective mode, the light is not transmitted through the color filter layer **33**, unlike a case in which color images are displayed. Accordingly, since bright images can be displayed in the reflective mode, it is easy to read the displayed information.

Further, when an image is displayed in the monochrome mode using a color signal, it is displayed in a gray-scale level, which is difficult to be discriminated. However, according to the present embodiment, it is possible to supply to the monochrome-display sub-pixel **51**(M) image signals different from those supplied to the color-display sub-pixels **51**(R), **51**(G), and **51**(B). Accordingly, it is possible to display high-quality color images in the transmissive mode and to display high-quality monochrome images in the reflective mode.

Furthermore, according to the present embodiment, the thickness of the planarization film **34** is different in the color-display sub-pixels **51**(R), **51**(G), and **51**(B) and the monochrome-display sub-pixel **51**(M), so that the liquid crystal layer **43** is thick in the color-display sub-pixels **51**(R), **51**(G), and **51**(B) and the liquid crystal layer **43** is thin in the monochrome-display sub-pixels **51**(M). Accordingly, even though light is transmitted through the liquid crystal layer **43** twice in the reflective mode and only once in the transmissive mode, it is possible to optimize the retardation both in the color-display sub-pixels **51**(R), **51**(G), and **51**(B) and in the monochrome-display sub-pixel **51**(M) since the liquid crystal layer **43** is thicker in the color-display sub-pixels in which transmissive display is performed.

Moreover, according to the present embodiment, the ratio of the sub-pixel area to the number of the TFD elements **70** (the sub-pixel area per switching element) is the same in each of the respective sub-pixels **51**(R), **51**(G), **51**(B), and **51**(M). Accordingly, since an equal capacitance ratio can be obtained in the transmissive mode and the reflective mode, an equal driving voltage can be applied.

Configuration for Conversion to Monochrome Image Data

According to a first method of such a conversion, when conversion from a color image to a monochrome image is performed, in adjacent pixels **50**, if signals are different in terms of color image data but the signals become the same gray-scale signals when changed to monochrome image data, the gray-scale levels of the signals are changed to perform display.

According to a second method of the conversion, when the gray-scale levels of R, G, and B are DR, DG, and DB, respectively, in color image data, monochrome image data is obtained by the following equation:

$$\text{monochrome image data } DM=0.33\times DR+0.5\times DG+0.17\times DB$$

For example, when (DR, DG, DB)=(100, 30, 30), monochrome image data DM=0.33×100+0.5×30+0.17×30=51. Also, when (DR, DG, DB)=(30, 100, 20), monochrome image data DM=0.33×30+0.5×100+0.17×20=63.

According to a third method of the conversion, when conversion from a color image to a monochrome image is performed, the contour of the image is detected from color image data, and then, using the contour, data set to a different gray-scale level from the adjacent pixel is used as the monochrome image data.

According to any one of the above-mentioned methods, unlike a case in which signals for displaying color images are used to display monochrome images, it is possible to easily read displayed information in the monochrome images even when the equal luminances between adjacent pixels are equal or approximately equal to each other.

Second Embodiment

FIG. **6** is an explanatory view showing a configuration of a pixel, in plan view, in an electro-optical device according to a second embodiment of the invention.

As shown in FIG. **6**, in the electro-optical device according to the present embodiment, rows (X direction), on which three color-display sub-pixels **51**(R), **51**(G), and **51**(B) are repeatedly arranged along the scanning line **41**, and rows (X direction), on which monochrome-display sub-pixels **51**(M) are arranged along the scanning line **41**, are alternately arranged in a direction (Y direction) in which the data lines **42** are extended. The respective sub-pixels **51**(R), **51**(G), **51**(B), and **51**(M) have the same area. The configuration or operation of each sub-pixel **51**(R), **51**(G), **51**(B), and **51**(M) is the same as in the first embodiment and a detailed description thereof will thus be omitted herein.

Also in the present embodiment, the color-display sub-pixels **51**(R), **51**(G), and **51**(B) display images in a transmissive mode in which light emitted from the backlight **6** is modulated, while the monochrome-display sub-pixel **51**(M) display images in a reflective mode in which light incident from outside is modulated. Also, the sub-pixels **51**(R), **51**(G), **51**(B), and **51**(M) are respectively connected to the respective data lines **42** through the respective TFD elements **70**. Accordingly, predetermined image data can be supplied to the sub-pixels **51**(R), **51**(G), **51**(B), and **51**(M), respectively. That is, in the pixel **50**, different image signals can be supplied to the color-display sub-pixels **51**(R), **51**(G), and **51**(B) and the monochrome-display sub-pixel **51**(M), respectively. Also, since the respective sub-pixels **51**(R), **51**(G), **51**(B), and **51**(M) have the same sub-pixel area with respect to one TFD element **70**, an equal capacitance ratio can be obtained both in the transmissive mode and in the reflective mode, and thus an equal driving voltage can be applied.

Third Embodiment

FIG. **7** is an explanatory view showing a configuration of a pixel, in plan view, in an electro-optical device according to a third embodiment of the invention.

As shown in FIG. **7**, in the electro-optical device according to the present embodiment, rows (x direction), on which three color-display sub-pixels **51**(R), **51**(G), and **51**(B) are repeatedly arranged along the scanning line **41**, and rows (X direction), on which monochrome-display sub-pixels **51**(M) having an area three times as large as that of the sub-pixel **51**(R), **51**(G), and **51**(B) are arranged along the scanning line **41**, are alternately arranged in a direction (Y direction) in which the data lines **42** are extended. The respective sub-pixels **51**(R), **51**(G), and **51**(B) have the same area. Also, the color-display sub-pixels **51**(R), **51**(G), and **51**(B) are respectively connected to the data line **42** through a single TFD element **70**, while the monochrome-display sub-pixel **51**(M) is connected to the data line **42** through three TFD elements **70**. Thus, the color-display sub-pixels **51**(R), **51**(G), and **51**(B) and the monochrome-display sub-pixel **51**(M) have the same number of TFD elements **70** with respect to an area of the sub-pixel. That is, the respective sub-pixels **51**(R), **51**(G), **51**(B), and **51**(M) have the same sub-pixel area with respect to one TFD element **70**. The configuration or operation of each sub-pixel **51**(R), **51**(G), **51**(B), and **51**(M) is the same as in the first embodiment and a detailed description thereof will thus be omitted herein.

Also in the present embodiment, the color-display sub-pixels **51**(R), **51**(G), and **51**(B) display images in a transmissive mode in which light emitted from the backlight **6** is modulated, while the monochrome-display sub-pixel **51**(M) display images in a reflective mode in which light incident from outside is modulated. Further, the sub-pixels **51**(R), **51**(G), **51**(B), and **51**(M) are connected to the data lines **42** through the respective TFD elements **70**, respectively. Accordingly, predetermined image data can be supplied to the sub-pixels **51**(R), **51**(G), **51**(B), and **51**(M), respectively. That is, in the pixel **50**, different image signals can be supplied to the color-display sub-pixels **51**(R), **51**(G), **51**(B) and the monochrome-display sub-pixel **51**(M), respectively.

Further, the respective sub-pixels **51**(R), **51**(G), and **51**(B) are electrically connected to the data line **42** through the single TFD element **70**, while the sub-pixel **51**(M) is electrically connected to the data line **42** through three TFD elements **70** since it has an area three times as large as that of each of the sub-pixels **51**(R), **51**(G), and **51**(B). The respective sub-pixels **51**(R), **51**(G), **51**(B), and **51**(M) are equal to each other in an area of the sub-pixel with respect to one TFD element **70**. Accordingly, since an equal capacitance ratio can be obtained in the transmissive mode and the reflective mode, an equal driving voltage can be applied.

Other Embodiments

Although the counter substrate **30** is provided at a side to which display light is emitted and the element substrate **20** is provided at the opposite side in the above embodiments, the element substrate **20** may be provided at the side to which the display light is emitted and the counter substrate **30** may be provided at the opposite side. In this case, both the color filter and the reflective layer are formed on the counter substrate **30**. Also, although a corresponding color filter layer is not provided in the monochrome-display sub-pixel in the above embodiments, a corresponding a single-colored color filter layer, such as a green color filter layer, may be provided in the monochrome-display sub-pixel.

Also, although an electro-optical device having a liquid crystal panel using a TFD element as an active element has been described in the above embodiments, the invention may be applied to an electro-optical device having a liquid crystal panel using a TFT as an active element. Also, the invention is preferably applied to a liquid crystal display device serving as an electro-optical device. Also, the invention may be applied to an in-plane switching (IPS) mode liquid crystal display device. Also, although the color-display sub-pixels are provided to correspond to red (R), green (G), and blue (B) in the above embodiments, they may be provided to correspond to yellow, cyan, and magenta.

Electronic Apparatus Equipped with Electro-Optical Device

FIGS. **8**A and **8**B are explanatory views showing an open state and a closed state of a flip-type mobile phone, which is an example of an electronic apparatus to which the invention is applied.

The electro-optical device to which the invention is applied is, for example, used in a mobile phone **300** shown in FIGS. **8**A and **8**B. In the mobile phone **300**, a cover **330** is rotatably connected to a main operation body **350** through a hinge **340**. The mobile phone **300** includes a main display part **311** provided inside the cover **330** to display an image when the cover **330** is open, and a sub-display part **321** provided outside the cover **330** to display an image when the cover **330** is closed. For example, the electro-optical device according to the invention constituting the main display part **311** can be applied to the flip-type mobile phone **300**.

Also, the electro-optical device **1** can be used in various electronic apparatuses, such as mobile computers, digital cameras, movie cameras, in-vehicle devices, audio devices, projectors, in addition to the mobile phone.

What is claimed is:

1. An electro-optical device, comprising:

pixels arranged in a matrix, each pixel including a plurality of color-display sub-pixels corresponding to a plurality of colors and a monochrome-display sub-pixel, each color-display sub-pixel including a color filter,

a planarization film disposed in the color-display sub-pixels and in the monochrome display sub-pixel and including a smaller thickness in the color display sub-pixels than in the monochrome display sub-pixel;

a liquid crystal layer having a larger thickness in the color-display sub-pixels than in the monochrome display sub-pixel,

an insulation film disposed below the liquid crystal layer in the color display sub-pixels and in the monochrome display sub-pixel, the insulation film having a substantially uniform surface opposing the liquid crystal layer in the color-display sub-pixels and having an uneven surface opposing the liquid crystal layer in the monochrome display sub-pixel;

a reflective layer disposed in the monochrome display sub-pixel and positioned on the uneven surface of the insulation film, between the liquid crystal layer and the insulation film, and without a filter provided in an area opposite to the reflective layer, the reflective layer including an uneven surface defining a series of peaks and valleys operable to scatter light in a plurality of directions;

a transmissive upper electrode disposed on the reflective layer between the liquid crystal layer and the reflective layer, the transmissive upper electrode including an uneven surface defining a series of peaks and valleys substantially aligned with the peaks and valleys of the reflective layer; and

an alignment film disposed on the transmissive upper electrode between the liquid crystal layer and the transmissive upper electrode, the alignment film including an uneven surface defining a series of peaks and valleys substantially aligned with the peaks and valleys of the transmissive layer and the peaks and valleys of the reflective layer;

wherein the color-display sub-pixels and the monochrome-display sub-pixel perform gray-scale display independently,

the color-display sub-pixels display an image only in a transmissive mode, and the monochrome display sub-pixel displays an image only in a reflective mode.

2. The electro-optical device according to claim **1**,

wherein, in each pixel, different image signals are supplied to the color-display sub-pixels and the monochrome-display sub-pixel, respectively.

3. The electro-optical device according to claim **1**,

wherein the sub-pixels are electrically connected to signal lines through pixel switching elements, respectively, and

the respective sub-pixels have the same sub-pixel area per switching element.

4. The electro-optical device according to claim **1**,

wherein the color-display sub-pixels and the monochrome-display sub-pixel are electrically connected to signal lines through pixel switching elements, respectively, and

one of the color-display sub-pixels and the monochrome-display sub-pixel are equal in the number of switching elements per unit sub-pixel area.

5. The electro-optical device according to claim **1**,

wherein, in the pixel, among four sub-pixels arranged in a lattice shape, three sub-pixels are the color-display sub-pixels and the remaining one sub-pixel is the monochrome-display sub-pixel.

6. The electro-optical device according to claim **1**,

wherein, in the pixel, a row on which the three color-display sub-pixels are arranged and a row on which the monochrome-display sub-pixels are arranged are provided parallel to each other.

7. An electronic apparatus comprising the electro-optical device according to claim **1**.

* * * * *